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Influence of Grounded Neutral on Single-phase Short-circuit Currents

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Abstract **—The neutral grounding systems are a critical element in the power system reliability. According to IEEE standard, the types of neutral grounding systems are: ungrounded system, effectively grounded system, resistance grounded. During a single-phase to ground fault, current flows from the transformer winding through the ground path and the neutral grounding system. This paper aims at developing a new mathematical model to study the impact of neutral grounding transformer during a single-phase to ground fault, the fault resistance effect and also the impact of the distance separating a fault point to the power generators. Then the paper's main focus is on the control of the level of single-phase short-circuit current on the faulted distribution network analysis. In order to do the analysis the IEEE 14-bus standard system is proposed and a program developed to calculate fault current depending of neutral grounding system under MATLAB environment.**

Index Terms— **fault location, grounding system, Matlab, single-phase short-circuit, symmetrical components method.**

I. INTRODUCTION

Electric power is generated, transmitted and distributed via large interconnected power systems. Distribution systems are an important part of the electric power system. These systems supply power to customers and shall ensure the reliability and stability of the system.

Short circuit currents are responsible for several types of disturbances in the network. These currents cause severe effects on equipments and power lines, such as thermal and mechanical stresses.

The severity of the fault depends on the short-circuit location, the path taken by fault current, which depends to grounding system, and the fault impedance value [1]. These short circuit currents determine the rating of circuit breakers that must be able to clear the fault in order to avoid permanent damage to the equipment.

The neutral point grounding mode is a very important problem in power network planning, designing and operation of distribution network. So, it have become an urgent problem, which fundamentally research better neutral grounding mode to further improve the requirements about power grid operation of safety, economy and reliability. Therefore, the choice of grounding modes has become a hot-button issue among the power supply.

This paper describes a new mathematic model, which is developed using the method of symmetrical component and Kirchhoff's lows [2], [3]. This study allowed us to study the behavior of transformer with neutral isolated, effectively ground and ground through impedance and shows the impact of neutral grounding transformer in fault currents and voltages value.

The fault analysis was developed in first to calculate the fault current and voltage during a single-phase to ground fault. The IEEE 14bus standard system was employed to explore the inherent characteristic of each neutral grounding mode. The impact of system grounding was the major concern. Simulation result including phase voltage and fault current during the disturbance, fault resistance and distance separating a fault point to the power generators, were presented and their effects were discussed.

II. SHORT-CIRCUIT CALCULATION

Short-circuit calculations are inescapable in the application and setting of protective systems and in the analysis of system operations. Thus, short-circuit current withstand capability of the main devices decides whether the network could run more safely or not. So it's significant to calculate the short-circuit current and offer some possible solutions.

Indeed, this calculation depends of the type of short- circuit. Thus, several type of short- circuit can occur in a three phase system, as follow: line-to-ground fault 70% of all transmission lines faults are classified under this category, line-to-line fault (15%), double line-to-ground (10%) and only 5% represent the three phase fault [4]. However, we analyzed only line-to-ground faults because is the most common fault type in electrical distribution networks fault. This approach is based on IEC 60909 and NFC15-100 standard.

Fortescue's theorem suggests that any unbalanced fault can be solved into three independent symmetrical components which differ in the phase sequence. These components consist of a positive sequence, negative sequence and a zero sequence.

The single line-to-ground fault is usually referred as short-circuit fault and occurs when one conductor falls to ground or makes contact with the neutral wire. Fig. 1 shows the sequences network diagram of a single line-to-ground fault. Z0, Z1 and Z2 are respectively zero, positive and negative

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impedance, Zf is the fault impedance, V0, V1 and V2 represent respectively the zero, positive, and negative voltage.

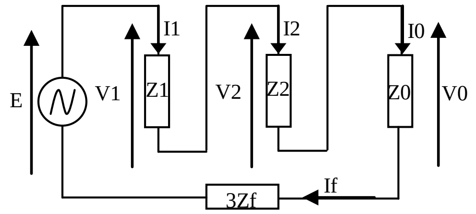

Fig. 1. Sequence network diagram of a single line-to-ground fault.

III. DESCRIPTION OF THE SYSTEM

A single line diagram of the IEEE 14-bus standard system extracted from [5] is shown in Appendix (Fig. 5). It consists of five synchronous machines. There are eleven loads in the system. Three step-up transformers, one of which is three winding transformer. We assumed that the coupling of the transformers is in star-delta. The dynamic data for the generators were selected from [6]. The IEEE 14-bus was studied using MATLAB to explain the influence of grounding transformer on single phase short-circuits.

IV. METHODS OF CALCULATION

When an unbalanced three-phase fault occurs, we can solve the three-phase circuit using impedance matrix method or Thevenin's method. In this paper the symmetrical component method is used to simplify the analysis procedure of unbalanced system and also helps in improving the understanding of the system behavior during fault conditions.

These components consist of a positive, negative and a zero sequence. Before the occurrence of a fault, there are no fault current, and all voltage are balanced, positive sequence voltage. Then, neither currents nor voltage are present in the negative and zero sequence network. When the fault occurs the system goes from a balanced condition to an unbalanced condition. Thus it is necessary to calculate currents and voltages in the system under fault.

Short-circuit current calculation according to IEC 60909-0 is carried out based on:

- The solutions found by the load flow algorithm, which are useful to provide results which are meaningful to start a program to calculate a single-phase short-circuit current, see in Appendix Table V.
- Compute the impedance matrix of the system, positive, negative and a zero impedance,
- Compute the short-circuit current by developing all below equations.

To simplify the development, we adopt the matrix form. From the fig.1 and using Kirchhoff's laws we can write (1):

$$\begin{cases} [0]=[V_0]+[Z_0][I_0] \\ [E]=[V_1]+[Z_1][I_1] \\ [0]=[V_2]+[Z_2][I_2] \end{cases} \tag{1}$$

Where:

$[E]$: pre-fault voltage of generators,

$[V_0],[V_d]$ and $[V_i]$: respectively the zero, positive, and negative voltage of each,

$[Z_0],[Z_d]$ and $[Z_i]$: respectively the zero, positive, and negative impedance,

$[I_0],[I_d]$ and $[I_i]$: respectively the zero, positive, and negative current in each bus.

The zero, positive and negative currents are also connected through the impedance of the network by the system of equations (2):

$$\begin{cases} [I_0]=[Y_{mn0}].[V_0]-V_{F0}.[Y_{nF0}]^T \\ [I_1]=[Y_{mn1}].[V_1]-V_{Fi}.[Y_{nF1}]^T \\ [I_2]=[Y_{mn2}].[V_2]-V_{F2}.[Y_{nF2}]^T \end{cases} \tag{2}$$

Where:

$[Y_{mn0}],[Y_{mn1}]$ and $[Y_{mn2}]$: admittances matrix connecting the machine m to machine n

$[Y_{nF0}]^T,[Y_{nF1}]^T$ and $[Y_{nF2}]^T$: admittances matrix transposed to the fault bus F.

V_{F0}, V_{F1} and V_{F2} : respectively the zero, positive, and negative voltage at point F.

The fault current of zero, positive, and negative sequence at the fault point can be expressed by (3):

$$\begin{cases} I_{F0}=-[Y_{nF0}].[V_0]+y_{FF0}.V_{F0} \\ I_{F1}=-[Y_{nF1}].[V_1]+y_{FF1}.V_{F1} \\ I_{F2}=-[Y_{nF2}].[V_2]+y_{FF2}.V_{F2} \end{cases} \tag{3}$$

In (3) y_{FF0}, y_{FF1} and y_{FF2} are respectively the zero, positive, and negative admittance at point F.

After a long development of previous systems, we obtain the voltage at faulted point which is related to the single phase short circuit current I_{cc} by fault impedance Zf:

$$V_{F0}+V_{F1}+V_{F2}=Z_f I_{cc} \tag{4}$$

Note that the sequence voltage, current and impedances are all in *per-unit*.

V. SIMULATION AND INTERPRETATION

From the analysis of unbalanced fault condition it has been remark that the connection of the transformer and generator neutrals greatly influences the fault current and voltage [7].

Thus, it can affect the current settings for the protection and the ratings of the circuit breakers. For this reason we propose through this paper to demonstrate the influence of transformer neutral by simulating, under environment Matlab, several scenarios, and attempt recommendation to solve the problem.

On the other hand, we study the effect of fault impedance in the severity of the short circuit. Finally, we will contemplate the influence of the distance between the fault point and the power generators. Considering the necessity to calculate fault currents and voltages in the fault analysis study, we begin then by the calculation of the prefault network condition via a load flow program.

Initiated of mathematic model explain earlier and the result of load flow program, we calculate the short circuit current by the symmetrical component method. The generators are represented by a constant voltage behind an approximate admittance. The transformer will be modeled by short circuit impedance for both positive and negative sequence; zero sequence impedance depends upon the nature of connection of the neutral grounding transformer. The loads are modeled as constant impedance and transmission line could be presented by the standard π model [8].

For the IEEE 14-bus, we assume that a single-phase short circuit will occurred in bus 5, a comparative study taking account of the setting of the transformers neutral, is the object of the first simulations. Section F discusses the effect of the fault impedance. Whereas simulations to analyze the influence of the electric distance are the object of the last paragraph which will make it possible to assess the suitable site of protections.

A. Influence of the mode of the transformer neutral on the fault current

The short circuit current accidents of power transformers increase year by year, and it seen by their mode of grounding connection. However, the system earthing is of high importance to the behavior of a power system during an asymmetrical fault. In most power system the neutral can be solidly grounded, ungrounded or grounded via resistance.

In the following, we will give some focus to the system earthing and demonstrate their impact on the single-phase short-circuit current by computer simulations using the MATLAB environment and evaluate different scenarios of faults as the single phase to ground fault which can occur in any of the three phases. Thus, phase "a" is usually assumed to be the faulted phase, this is for simplicity in the fault analysis calculations.

Methods of grounding a power system affect the zero sequence impedance networks. As such, grounding has an effect on the unsymmetrical fault currents in the network [10]. Furthermore, the effective way to change the zero –sequence impedance is changing the earthing methods of transformer neutral points.

In the investigation of grounding transformers, three cases are simulated, effectively grounded, ungrounded and grounded via impedance. The single phase short-circuit was assumed to occur at bus 5. We will consider that all scenarios have a fault resistance Zf equal to 3Ω .

1) Transformer Neutral is Effectively Grounded: We know that the type of neutral earthing determines the impedance Z0 of the zero-sequence component and has a dominating influence on the short-circuit current through earth. In this case no impedance between the neutral and earth. So, the zero-sequence impedance of the winding transformer shall be null. The simulations were carried out for this case as demonstrated in Table I and graphically in fig. 2. The effectively earthed system is characterized by high levels of fault current and a considerable drop voltage at faulted phase.

TABLE I
SHORT CIRCUIT CURRENT I_{cc} (pu)

Scénario of short-circuit	Isolated neutral $Z_0 = \infty$	grounded via impedance $Z_0 = 0.0451.j$	effectively grounded $Z_0 = 0$
I_{cc}	0	7.3343	10.6779

The fig. 2 depicted the phase voltage waveform relative to fault node, we can note a voltage drop in the fault line a, whereas the voltage of healthy phase, Vb and VC, do not change. Then this system earthing provides the best control of transient over-voltages that can arise between earth and electrical system. Thus, the main advantage of effectively earthed systems is low over voltages, which makes the earthing design common at high voltage levels (HV).

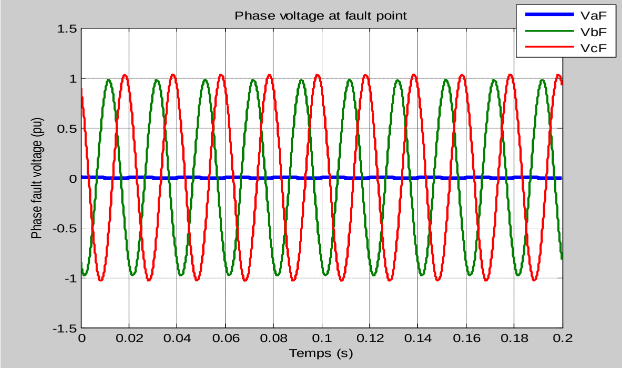

Fig. 2. Fault voltage curve in the case of an effectively grounded neutral.

2) Transformer neutral is grounded via impedance: For this study case, reactance will be connected between a transformer neutral point and the station earthing system. Thus, we note that the current is less weak than for the first scenario as seen at the Table I. Also, it can be seen in curves shown in fig. 3 that the voltage at the fault point increased compared with the case of transformer neutral is effectively grounded.

Therefore, inserting impedance into neutral earth connection attempts to limit the destruction caused by arcing earth faulted and improve the earth fault detection.

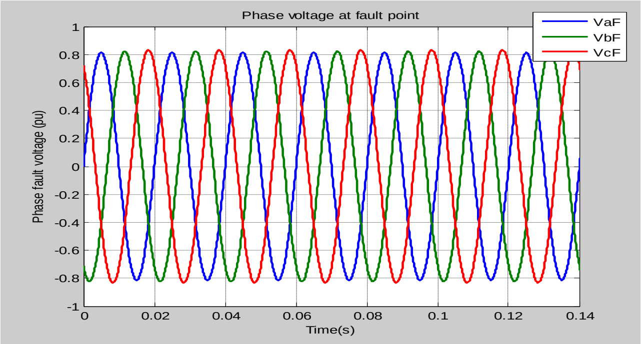

Fig. 3. Fault voltage curve in the case of a neutral connected via impedance.

3) Isolated transformer neutral: If the neutral of the transformer will be isolated, the current in the Y-winding is zero and thus the impedance is infinite. Therefore, the star winding does not permit any zero sequence current to flow. The result is shown in Table I. This system has one big advantage that they can continue operating in the presence of a single earth fault. This is because there is no return path available for the flow of earth fault current.

The major disadvantage of this system grounding is the intermittent arc over-voltage. Then the non-faulted phases experienced an over voltage can reach even the value 1.73pu, shown in Fig. 4. Therefore, it may be pose a threat to equipment's safety and insulation.

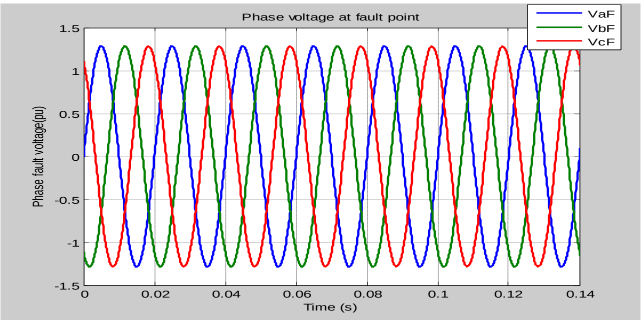

Fig. 4. Fault voltage curve in the case of isolated transformer neutral.

B. Conclusion

In this section we explained the high importance of the grounding system in the behavior of a power system during single phase short-circuits. We can remark that in isolated neutral systems some phase-to-earth faults are cleared without involving any relay operation because fault current is zero.

This is normally a good thing but can, in case of intermittent faults and neutral point displacement voltage, lead to over voltages and additional faults in the power system. In the case of effectively grounded system the main advantage is low over voltage, which makes the earthing design common at high voltage levels (HV). However, a high fault current flow in the network, which can cause the potential rise of exposed parts of the power system to reach dangerous levels. The resistance earthed systems are trade-off between effectively and isolated grounded. Therefore, the purpose of the neutral point resistor is to increase the resistive part of the earth fault current and hence improve the earth fault detection.

Given that the system with isolated neutral assures a good continuity of service, we propose the disconnection of the neutral of some transformers.

In the following section, we study the fault resistance effect on during-fault voltages and currents when all transformers are connected via resistance.

C. Variation of fault resistance r_f

Some focus is also given to the fault resistance, which affects the neutral voltage and earth fault current. Single phase to ground faults were simulated considering several fault resistance (r_f = 0, 0.34, 3.4, and 34Ω). The symmetrical components method was used to calculate during fault voltages and currents.

Table II shows the fault voltages for phase a, at buses 1, 2, 4, 5 and 6, during a ground faults for each fault resistance. Due to the system grounding the non-faulted phases experienced an overvoltage. However, for fault resistance larger than 3Ω the voltages are almost not affected by the fault.

The single phase short circuit current is depicts in Table III. The fault currents are reduced when the fault resistance is increased. Moreover, for fault resistance larger than 34Ω, the fault current is almost zero. We can also remark that, the during-fault voltages are similar to the pre-fault voltages when the fault resistance is larger than 34Ω for buses.

Consequently, a good choice of fault resistance permits to reduce the fault current injected into each bus, and therefore the fault voltages tend to the pre-fault voltages.

TABLE II
FAULT PHASE-VOLTAGE AT BUSES 1, 2, 4 AND 5

Buses	r_f(Ω)	V_a (pu)	V_b (pu)	V_c (pu)
Bus 5	0	0.0000	0.6563	1.0743
	0.34	0.8613	1.0082	0.6716
	3.4	0.8001	0.8094	0.8200
	34	0.8144	0.8154	0.8165
Bus 1	0	0.6718	0.8459	1.1818
	0.34	0.9268	1.0093	1.0529
	3.4	1.0341	1.0442	1.0484
	34	1.0471	1.0481	1.0485
Bus 2	0	0.6511	0.8119	1.1215
	0.34	0.8869	0.9674	1.0054
	3.4	0.9895	0.9994	1.0029
	34	1.0019	1.0029	1.0033
Bus4	0	0.3579	0.6146	0.9072
	0.34	0.6768	0.7617	0.7971
	3.4	0.7816	0.7916	0.7949
	34	0.7940	0.7950	0.7953
Bus 6	0	0.2417	0.3430	0.4964
	0.34	0.3670	0.3931	0.4235
	3.4	0.4071	0.4101	0.4135
	34	0.4119	0.4122	0.4125

TABLE III
SINGLE PHASE SHORT CIRCUIT

r_f(Ω)	0	0.34	3.4	34	∞
Icc (pu)	9.2769	1.9837	0.2353	0.0240	0

D. The effect of fault distance between power generators and the fault point

Let us investigate in this section the effect of fault distance between power generators and the fault point on the short-circuit current. The method is based on the calculation of the faulty line impedance. Then, several scenarios of fault disturbances such as single phase short-circuit occurred between buses 5 and 1 are simulated to assess the effect of electrical distance.

Simulations were carried out on this study case and the results are depicted in Table IV. Therefore, we can remark that in the case of a far-from-generator short-circuit, the short-circuit causes the minimal short-circuit current. While for near-to-generator short-circuits, short-circuit current shall always has a maximal value in the case of a single-phase short-circuit.

Thus, we can conclude that when the fault is occurred far from the power generator, the voltage drop is attenuated and the short-circuit current is reduced [9].

TABLE IV
EFFECT OF FAULT DISTANCE BETWEEN POWER GENERATORS AND THE FAULT POINT.

L(Km)	V1(pu)	V3(pu)	V5(pu)	Icc (pu)
1	0.8953	0.8963	0.8923	9.4446
10	0.8896	0.8914	0.8831	3.4278
100	0.8789	0.8848	0.7985	2.9690
1000	0.9732	0.9747	0.7874	0.4251

VI. Conclusion

In the present work, an attempt to develop a new mathematic model for studying the impact of single phase fault has been presented. The analysis has considered the effects of three kinds of neutral grounding system in detail.

From the simulation results, we can conclude that the way which neutral is connected to the earth determines the behavior of a power system during a single phase short circuit.

Furthermore, we confirm that to minimize the fault current in an electrical supply network, it is necessary to manage the setting of the neutrals of the transformers, to choose the fault resistance and to transfer the fault point to place far from the power generator. We can also note that if the neutral of transformer is isolated the fault current is very small and consequently we decrease the customer's outage.

Appendix

TABLE V
THE PREFAULT VOLTAGE FROM LOAD FLOW PROGRAM

Buses	Prefault voltage	Buses	Prefault voltage
1	1.0600	8	1.0438
2	1.0450	9	1.0900
3	1.0100	10	1.0268
4	1.0100	11	1.0446
5	1.0238	12	1.0529
6	1.0313	13	1.0461
7	1.0700	14	1.0169

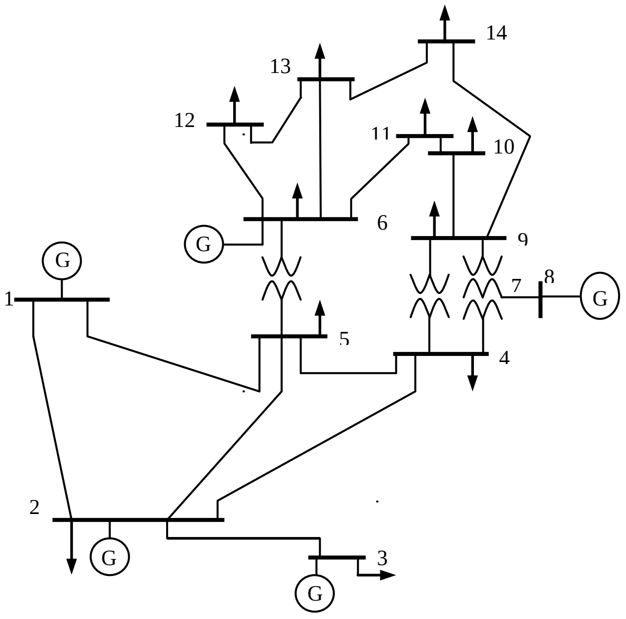

Fig. 5. IEEE 14-bus test system.

REFERENCES

[1] J.C.Sabonnadière and Nouredine Hadjsaïd, "Line and electric network 2,"Lavoisier,Hermes, 2007.
[2] J.L. Kirtley Jr, "Introduction to symmetrical components," Dept. Elect. Massachusetts Univ., 2003.
[3] B.M.Weedy, "Electric power systems," third edition, Chichester New York Brisbane Toronto, 1979 by John Wiley & Sons.
[4] J. Arrillaga and C.P.Arnold, "Computer analysis of power systems," *1990* by John Wiley & Sons.
[5] S.K. Kodsi and C. A. Canizares, "IEEE 14 Bus system with facts controllers," IEEE *Trans*, 2003.
[6] P.Kundur, "Power system stability and control," McGraw-Hill,Inc 1993.
[7] P. M. Anderson and A. A. Fouad, "Power system control and stability," IEEE Press, 1994.
[8] D. Shipp and F.Angelini, "Characteristics of different power systems neutral grounding techniques," Conference Technique, IEEE, 1988.
[9] Paul M. Anderson and A.A. Fouad, "Power System Control and Stability," IEEE PRESS, 1994.
[10] S. Hänninen, "Single phase earth faults in high impedance grounded networks Characteristics, indication and location," Ph.D. dissertation, Dept. Elect. Eng., Helsinki Univ., Finland, December 2001.